How LIFE Works

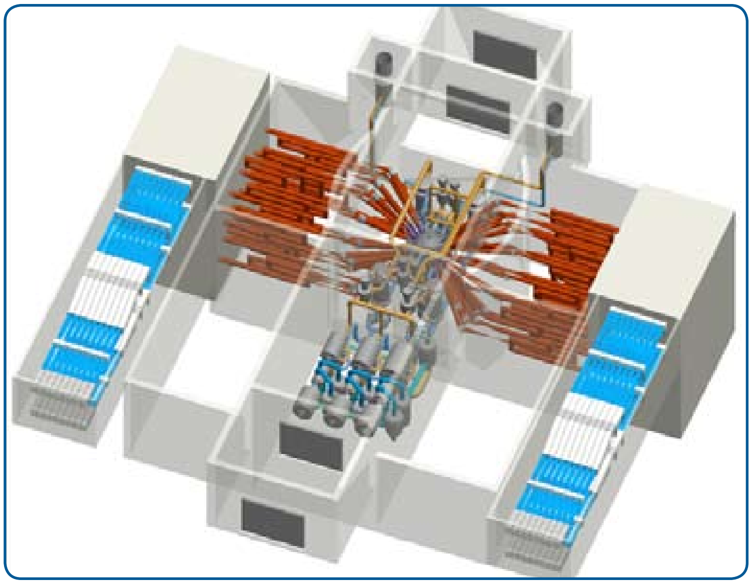
The concept of fusion-fission hybrids – using high-energy neutrons from fusion reactions to trasmute, or burn, fissile material – has been explored by scientists since about 1951.

Although the focus of many of these studies was the use of fusion neutrons to generate fuel for fast nuclear reactors, Nikolai Basov and others discussed the possibility of using laser-driven fusion targets to drive a fission blanket for generating power. Many proposals have also been made to use accelerators to generate neutrons that can then be used to burn nuclear waste and generate electricity.

Fusion-fission engines did not advance beyond the discussion stage at that time because powerful high-average-power lasers and other required technologies did not exist. Similarly, accelerator-based schemes never advanced past the conceptual study phase, in part because a complete nuclear fuel cycle – including uranium enrichment and nuclear waste reprocessing – was still required to generate economical electricity. The inefficiency and cost of those systems outweighed the benefit of transmuting nuclear waste.

Today, however, researchers are close to demonstrating the physics and key technologies required to make LIFE a reality. The capability of lasers to create the conditions required for ignition and thermonuclear burn in the laboratory with inertial confinement fusion (ICF) is expected to be demonstrated on the National Ignition Facility (NIF) within the next two to three years. The National Ignition Campaign began during 2009, and ignition and fusion energy yields of 10 to 15 megajoules (MJ) are anticipated during fiscal years 2010 or 2011. Fusion yields of 20 to 35 MJ are expected soon thereafter. Ultimately fusion yields of 100 MJ are expected on NIF.

With the appropriate research, development and engineering program, LIFE engines could begin to provide electricity to U.S. consumers within 20 years, and could provide a very significant fraction of U.S. and international electricity demand by 2100.



The LIFE Engine
A LIFE engine provides an option for a once-though closed nuclear fuel cycle.

The LIFE Power Plant

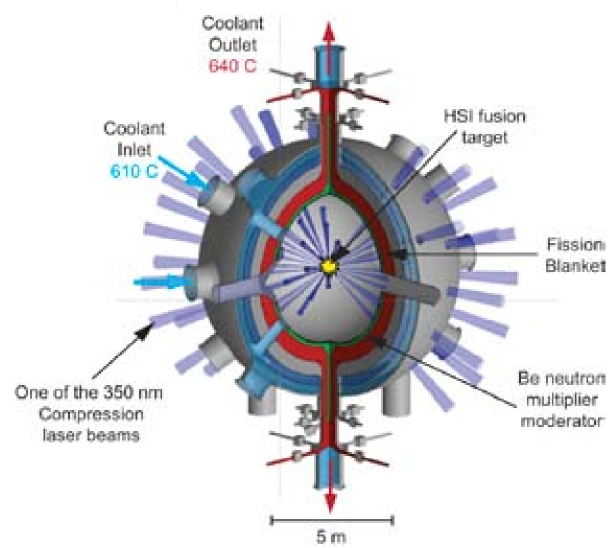
The LIFE development team is exploring a variety of possible fuel, target and laser configurations and energies for a prototype LIFE engine. The LIFE system is designed to operate with fusion energy gains of about 25 to 30 and fusion yields of about 35 to 50 MJ to provide about 500 megawatts (MW) of fusion power – about 80 percent of which comes in the form of 14.1 million electron-volt (MeV) neutrons with the rest of the energy in X-rays and ions.

This approach to fusion generates approximately 10^{19} 14.1-MeV neutrons per shot (about 10^{20} neutrons every second). When used to drive a subcritical fission blanket, the fusion neutrons generate an additional energy gain of four to ten depending upon the details of the fission blanket, providing overall LIFE system energy gains of 100 to 300.

The fission blanket contains either 40 metric tons (MT) of depleted uranium; un-reprocessed spent nuclear fuel (SNF); natural uranium or natural thorium; or a few MT of the plutonium-239, the minor actinides such as neptunium and americium, and the fission products separated from reprocessed SNF.

HOW LIFE WORKS

The point source of fusion neutrons acts as a catalyst to drive the fission blanket, so there is no need for a critical assembly to sustain the fission chain reaction. Starting from as little as 300 to 500 MW of fusion power, a single LIFE engine can generate 2,000 to 3,000 megawatts in steady state for periods of years to decades, depending on the nuclear fuel and engine configuration. Most pure inertial fusion energy plant designs require laser energies of about three MJ to achieve fusion yields of 200 MJ from NIF-like targets at about 15 shots a second to generate 3,000 MW of thermal power. In contrast, the laser energy requirements of the LIFE engine to generate the same amount of thermal energy are a factor of 2 to 2.5 lower.



LIFE Target Chamber

A LIFE fusion-fission chamber for a 37.5-MJ hot-spot ignition (HSI) target driven by a 1.4-MJ, 350-nanometer (ultraviolet) laser.

The neutrons pass through the first structural steel wall and a first-wall coolant to a layer of beryllium pebbles, which generate 1.8 neutrons for every neutron they absorb. The newly generated neutrons have a significantly lower energy spectrum that is ideal for fission energy generation.

The moderated neutrons strike the next layer, a one-meter-thick, subcritical fission blanket containing 40 MT of fission fuel pellets. The neutrons absorbed by the fuel pellets drive neutron capture and fission reactions, releasing tremendous amounts of heat to drive turbines. The pellets are immersed in a molten salt called flibe ($2LiF + BeF_2$) that carries away heat and also produces tritium that can be harvested to manufacture new deuterium-tritium fusion targets.

As conceived by Lawrence Livermore National Laboratory physicists and engineers, the LIFE engine's fusion targets, about one centimeter long and one-half centimeter in diameter, are injected at 10 to 15 Hz (10 to 15 times a second) into the center of the fusion chamber.

The current LIFE baseline power plant assumes targets similar to those that will be used for the ignition campaign on NIF. The first experiments to demonstrate LIFE ignition and gain will use 350-nanometer (ultraviolet) laser light with a central hot-spot ignition (HSI) target and an indirect-drive configuration. In this process, for which the scientific basis has been intensively developed for NIF, a solid-density gold shell about the size of a pencil eraser called a hohlraum surrounds the target capsule. When irradiated by lasers, the hohlraum emits a bath of X-rays that heat and vaporize the outer layer of the BB-sized target capsule, causing it to rapidly implode. The resulting temperature and pressure forces the hydrogen nuclei to fuse and ignite in a controlled fusion reaction.

In the future, a more optimal target option in which the fuel targets are ignited using a process called fast ignition could be used. In fast ignition, the targets are first compressed by one laser and then ignited to fusion conditions by a second.

NIF ignition and burn experiments with HSI targets are expected to be successful. The 35 to 40 MJ of yield needed for the baseline LIFE plant would require about 1.4 MJ of laser energy.

An enhanced version of tri-structural isotropic (TRISO) fuel is being used for the baseline design, since levels of burnup close to those required for LIFE have been achieved for fissile fuel with this fuel form. New fuels such as solid hollow core

(SHC) and encapsulated powder form (EPF) designs will help overcome limitations of TRISO for high burnup of fertile fuels.

Because of the continuous availability of external neutrons from the fusion source, a LIFE engine can extract more than 99 percent of the energy content of its fuel, resulting in greatly enhanced energy generation per metric ton of nuclear fuel. The external source of neutrons also allows the LIFE engine to burn the initial fertile or fissile fuel to more than 99 percent FIMA (fission of initial metal atoms) without refueling or reprocessing, allowing for nuclear waste forms with significantly reduced concentrations of long-lived, weapons-usable actinides per gigawatt-year of electric energy produced.

At the end of the engine's lifetime, 39.6 MT of fission products are left. This remaining waste has such a low actinide content that it falls into DOE's lowest attractiveness category for nuclear proliferation.

In addition, because of the very high fission product content, the waste is self-protecting for decades: its radiation flux is so great that any attempt at stealing it would be suicidal.

Following the initial interim storage and cooling at the reactor site, a geological repository similar to Yucca Mountain could be used for long-term storage or disposal. The size of a geological repository needed to accommodate an entire fleet of LIFE engines (with the same generating capacity as our current LWR fleet with a once-through fuel cycle) will be approximately 5 percent of that required for disposal of LWR SNF.

Fusion-Fission Power Plant

In a LIFE power plant, targets would enter the Target Chamber at a rate of 10 to 15 times a second.